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Radiological Air Sampling

Protocol Development for the Canadian Forces

D.S. Haslip, D. Estan and R. Buhr

Defence R&D Canada – Ottawa
TECHNICAL MEMORANDUM
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Abstract

As part of its ongoing support to DSP 00002199, the RAD group at DRDC Ottawa was asked to investigate how best to use the low-volume air sampler procured by the project for the Canadian Forces. The RAD group has used this air sampler to take a number of air samples at sites around the DRDC Ottawa campus. These air samples have been analysed via a number of techniques, many of which rely on measurements of the sampler filters by the RDS-100 survey meter system also procured by the project. A scheme for data analysis is suggested, with an emphasis on simplicity and field expediency. The sensitivity of this scheme is evaluated in terms of the minimum detectable activities of a collection of isotopes, and the airborne hazard that these would pose to deployed forces. It is shown that the air sampler is capable of providing warning of airborne hazards consisting of low-mass beta- and gamma-emitting radionuclides. However, for hazards consisting of alpha-emitting transuranic elements, this system is incapable of detecting the hazard at levels corresponding to NATO or civilian action levels.

Résumé

Le groupe ADR à RDDC Ottawa a étudié comment mieux employer l'échantillonneur d'air obtenu par le projet 00002199, dans le contexte de notre support à ce projet. Nous avons utilisé cet échantillonneur pour prendre des échantillons d'air à plusieurs sites autour du campus de RDDC Ottawa. Nous avons analysé ces échantillons avec un certain nombre de techniques, en particulier en utilisant le mètre de surveillance radiologique RDS-100, également obtenu par le projet. Nous avons suggéré une méthode pour l'analyse de données, avec une emphase sur la simplicité. La sensibilité de cette méthode est évaluée en termes de la concentration minimale détectable de plusieurs isotopes, et le risque que ceux-ci poseraient aux forces déployées. Nous avons démontré que l'échantillonneur d'air est capable de fournir des avertissements aux risques provenant des isotopes émetteurs beta et gamma. Cependant, pour des risques provenant des isotopes émetteurs alpha (les isotopes transuraniens), ce système est incapable de détecter un risque aux niveaux correspondant aux seuils d'intervention de l'OTAN ou des règlements civils.

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Executive summary

Introduction: The RAD group at DRDC Ottawa has provided continuing support to the 00002199 project. On this occasion, the project asked the RAD group to determine how to optimally use the recently procured DL-28B Low-Volume Air Sampler. The RAD group thus used the air sampler to take a number of air samples at various sites around the DRDC Ottawa campus. These have been analysed with several pieces of equipment and with various data analysis approaches, many of which involved measurements of sampler filters with the RDS-100 survey meter system.

Results: A scheme for measuring air sampler swipes is proposed, as is a method for analysing the data from these measurements. The measurement and analysis schemes emphasize field expediency, particularly timeliness and ease of execution. Estimates of the sensitivity of these schemes are given, and converted into minimum detectable concentrations of a selection of airborne radionuclides and the concomitant inhalation dose rates.

Significance: For low-mass beta- and gamma-emitting hazards, the DL-28B air sampler and the RDS-100 are sufficient to provide warning of airborne hazards, as long as the data analysis procedures described herein are followed. However, this system is insufficient to provide appropriate warnings for airborne hazards consisting of alpha-emitting transuranic elements. If this kind of hazard is suspected, the ABPM-203M air monitor (also procured by the project) must be used.

Haslip, D.S.; Estan, D.; and Buhr, R. 2003. Radiological Air Sampling: Protocol Development for the Canadian Forces. DRDC Ottawa TM 2003-149. Defence R&D Canada – Ottawa.

Sommaire

Introduction: Le groupe ADR de RDDC Ottawa a fourni beaucoup d'appui au projet 00002199. À cette occasion, nous avons étudié comment mieux utiliser l'échantillonneur d'air DL-28B. Nous avons pris des échantillons d'air à plusieurs sites autour du campus de RDDC Ottawa, et nous les avons analysés avec plusieurs équipements et avec plusieurs méthodes pour l'analyse des données. Souvent, l'équipement utilisé fut le mètre de surveillance radiologique RDS-100.

Résultats: Nous proposons une méthode pour la mesure des échantillons, et l'analyse des données, avec une emphase sur la simplicité. La valeur de cette méthode est évaluée en termes de la concentration minimale détectable de plusieurs isotopes, et le risque que ceux-ci poseraient aux forces déployées.

Signification: Nous avons démontré que l'échantillonneur d'air est capable de fournir des avertissements aux risques provenant des isotopes émetteurs beta et gamma, si les méthodes ci-décrites sont utilisées. Cependant, pour des risques provenant des isotopes émetteurs alpha (les isotopes transuraniens), ce système est incapable de détecter un risque aux niveaux correspondant aux seuils d'intervention de l'OTAN ou des règlements civils. Pour ces isotopes, nous avons besoin d'un système radiologique de surveillance d'air, comme le ABPM-203M (aussi obtenu par le projet).

Haslip, D.S.; Estan, D.; et Buhr, R. 2003. Radiological Air Sampling: Protocol Development for the Canadian Forces. DRDC Ottawa TM 2003-149. R&D pour la défense Canada - Ottawa.

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1. Introduction

Radioactive materials pose a significant and ever-growing hazard to Canadian Forces personnel operating in theatres around the world. In order to meet this challenge, the Department of National Defence is procuring equipment that will allow it to detect, identify and quantify the exposure of personnel to radiological hazards. This is being done under the auspices of Defence Services Procurement Project 00002199 [1].

Radiological hazards can take a variety of forms. One of the most potentially disruptive to military operations is an airborne hazard, namely radioactive materials in an aerosolized form. This kind of hazard is particularly troublesome for two main reasons. First, airborne radioactive materials can present a significant health hazard if inhaled or ingested, even in very small quantities. Second, clothing and equipment that is contaminated by exposure to airborne materials may be difficult or impossible to decontaminate thoroughly. Thus, it is important for the Canadian Forces to be aware of the presence of an airborne radiological hazard as soon as possible, both to ensure that personnel are appropriately protected and to ensure that contamination of equipment is minimized.

Project 00002199 has procured a number of "low-volume" air samplers. These air samplers are capable of drawing air at rates up to 100 litres per minute through a particulate filter, a charcoal canister, or both. Most CF applications will use only the particulate filter. However, radiological air sampling can be complex, and so there are a number of outstanding questions surrounding the use of these air samplers. Specifically, we would like to know

- How does one use this air sampler most effectively?
- How does one interpret the data obtained from sampling?
- What is the sensitivity of the system to airborne radioactive materials?

DRDC Ottawa has been tasked by project 00002199 to answer these questions. This document is the final report on this work. In this work, DRDC Ottawa has looked at air sampling data taken under a variety of conditions, and employed a variety of data analysis techniques to these data so as to determine the optimal methods for data analysis in the field. This work draws on some results from a previous report prepared by DRDC Ottawa on the topic of air sampling [2].

2. Theory

2.1 Challenges

At its most basic level, air sampling is fairly straightforward. Suppose the atmosphere around the air sampler has a concentration C of some radionuclide (in units of activity per unit volume). If the air sampler samples a volume V of air, and the particulate filter captures a fraction F of the particulates in that volume, then the activity captured on the particulate filter is CVF. In order to determine the airborne concentration, that filter must be removed from the sampler and counted by some method. If the efficiency of the radiation detector is D (in units of count rate per unit activity), then the count rate R of the radiation detector will be

$$R = CVFD.$$

In practice, C is the unknown quantity. V is known from the sampling time and the flow rate of the sampler (the sampler may even record this quantity). F is known from prior experiments, or more likely from data from the manufacturer of the particulate filter. D is also known from experiment or from manufacturer data[1], and R is the result of the measurement made on the particulate filter following the air sample. Thus, it is simple to calculate the airborne concentration of radionuclides.

The complicating factor in analyzing air samples is the omnipresence of radon in the atmosphere. Uranium-238 and thorium-232 are radioactive isotopes that occur naturally in the environment. Both of these isotopes have long decay chains (Figure 1.and Figure 2.) that include an isotope of radon (radon-222 in the uranium-238 chain, radon-220 for the thorium-232 chain[2]). Radon being a noble gas, these isotopes do not undergo chemical reactions, and as a result they can migrate considerable distances through earth or building materials to enter the atmosphere, both inside buildings and outside. When these isotopes decay, they form non-gaseous, chemically active elements that quickly attach themselves to particles of dust in the atmosphere. The particulate filters of air samplers trap these airborne radon daughters. Because radon is ubiquitous, all air samplers will catch these radioactive radon daughters in the particulate filter. So, any air sample taken in a contaminated environment will contain radioactivity from the contaminant, plus radioactive daughters of radon-222 (with a composite half-life of approximately 35 minutes [3]), plus radioactive daughters of radon-220 (with a composite half-life of approximately 10.5 hours [3]). This makes quantification of the contaminant difficult. Perhaps even more important, early detection of a contaminated environment is complicated because all air sampler filters are radioactive because of the radon daughters.

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[1] Actually, D will often depend on the isotope that is being measured, and so it may not be known *a priori*. However, ranges of values can be guessed at before isotope identification has been performed, with these estimates refined afterward.

[2] Radon-220 is also known as "thoron", because it originates with thorium. In this context, radon-222 is known simply as "radon".

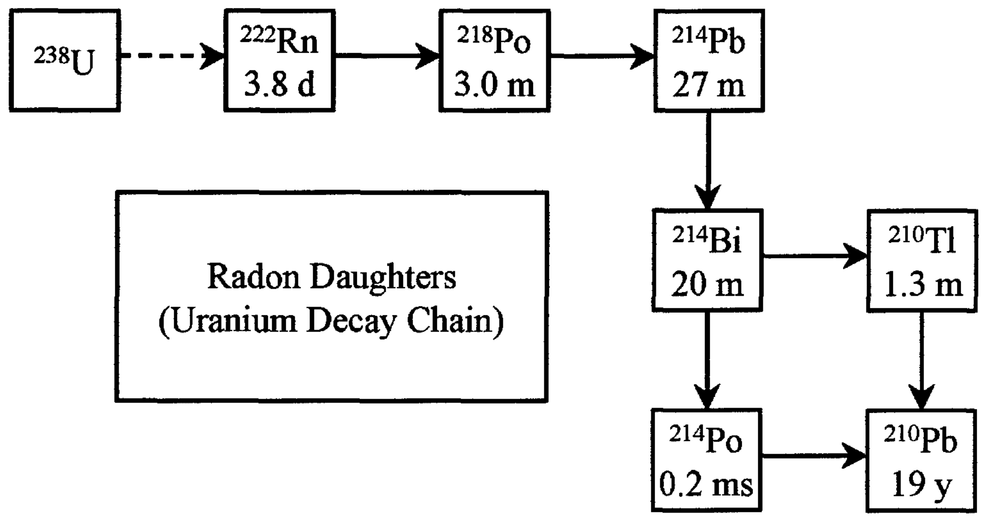

Figure 1. *Decay scheme of Uranium-238, showing only those isotopes coming after radon-222. Alpha decays are depicted as horizontal arrows, beta decays by vertical arrows.*

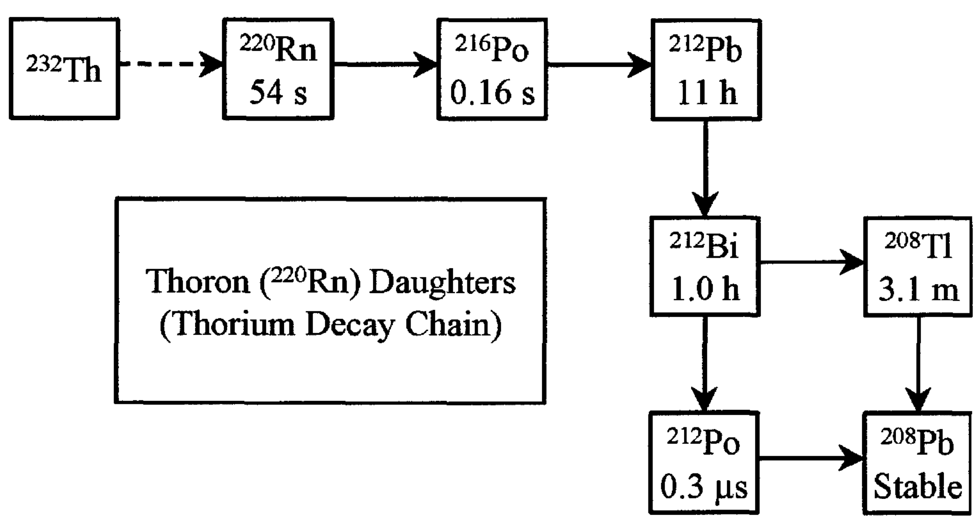

Figure 2. *Decay scheme of Thorium-232, showing only those isotopes coming after radon-220. Alpha decays are depicted as horizontal arrows, beta decays by vertical arrows.*

2.2 Potential Solutions

The problem, then, is that all air samples contain radon and thoron daughters that emit alpha, beta, and gamma radiation. Moreover, unless the radon and thoron concentrations are extremely high, they are of no interest. What the CF member must do, therefore, is to extract the signal due to any other potentially hazardous radionuclides (if any) from the air sampler data. This is not trivial.

The only foolproof approach is to take the particulate filter from an air sampler, cut it in half, and subject the two halves to separate analyses. One half should be analysed with a sensitive gamma spectrometer (such as a germanium detector), while the other half should be analysed with a liquid scintillation counter for its alpha and beta emissions. Then one can extract the non-radon signal by using spectrometric techniques (particularly for alpha or gamma-emitting contaminants) or the time dependence of the count rates.

However, as accurate as this method may be, it is not a reasonable approach for the Canadian forces. CF personnel do not have the sophisticated lab equipment required for these analyses, nor the ability to correctly interpret the data from such systems. Thus, simpler approaches to both measurement and data analysis are required.

For CF personnel, the method of measuring the air sampler filters is clear. The filters should be counted with the RDS-100 survey system, using both the alpha and beta probes. This is the only method available to the CF that is capable of detecting all of the isotopes that might be encountered during operations.

Since the problem of measurement is resolved, this report deals exclusively with the question of data analysis. This section in particular outlines a number of possible data analysis techniques that could be accomplished in the field. The first three methods apply equally well to either alpha count rates or beta count rates; the last method relies on measuring both the alpha and beta count rate. Validation of these methods is reserved until Section 3.

2.2.1 Constant Background

It may seem to the casual reader that the problem of radon backgrounds is overestimated. After all, measurements in many fields are subject to instrumental or environmental backgrounds. For instance, an alpha-beta survey meter is typically subject to instrumental backgrounds leading to non-zero count rates even in the absence of radiation. The solution to this problem is to determine the background level, and subtract it from all instrumental measurements.

Such an approach is easy to implement for air samples. One must collect a (preferably large) number of samples in the absence of non-radon contaminants. For each sample, one measures and records the initial count rate. The average initial count rate is the baseline against which subsequent measurements are judged. That is, the average initial count rate is subtracted from all subsequent measurements, and the difference is attributed to a contaminant.

While this method would appear to hold promise, it is well established that it doesn't work in a field environment. While radon is ubiquitous, its concentration in the environment is far from constant. Different locations on Earth can have concentrations that differ by orders of magnitude. In addition, and even more problematic, radon backgrounds at the same location vary

with time. Specifically, radon concentrations vary over the course of the day, in addition to exhibiting seasonal variations.

2.2.2 Half-Life Check

In DRDC's previous report on air sampling [2], the notion of a "partial background subtraction" was outlined. This proceeds as follows. If one was measuring a single background component with a half-life of 30 minutes, then one could make an initial measurement of the count rate (R_0), then make a second measurement after 30 minutes (R_{30}), and infer the rate R due to the contaminant via the equation

$$R = 2 * R_{30} - R_0 .$$

Of course, this only works if the contaminant has a half-life much longer than 30 minutes. This will almost always be the case for scenarios of military interest.

Unfortunately, the radon case is not this simple. There are two background components with quite different half-lives. However, the radon component is significant, and oftentimes dominant, so this method will help to decrease some of the backgrounds. So, rather than taking a large sample of background data (as in the previous section), one could take a large sample of "partially subtracted" background data, using the equation above. These results should also vary with time of day, but the variation should be smaller. Alternately, one could measure the count rate after an hour (instead of at 30 minutes) and use a slightly different form of the equation. This method may be more robust because a larger proportion of the radon has decayed away.

In this document, we propose a slightly different and simpler approach based on the same principles. Namely, we examine the ratio

$$X = R_0 / R_{30}$$

(or the corresponding ratio for measurements taken after 60 minutes). In the absence of long-lived isotopes, this ratio should be approximately 2 (or 4 for the sixty-minute ratio). However, when there is a substantial long-lived radioactive component on the filter, this ratio will approach unity. Thus, the person making the measurement should just look for results that are much closer to unity than is normal. This method is less quantitative, but is perhaps simpler to use as a "warning flag".

2.2.3 Multi-Point Calculation

In the previous DRDC report on this topic, a so-called "multi-point calculation" was also proposed. This technique uses three count rates taken

at three different times (such as immediately following the air sample, 30 minutes later, and 30 minutes after that). These results are then inserted into an equation whose coefficients depend on the measurement times, and the result is the count rate due to a long-lived contaminant. The previous document provided tables of coefficients in the appendix for various combinations of measurement times.

In principle, this approach should work because there are only three unknowns (the concentrations of radon, thoron, and the contaminant), and thus three independent measurements should reveal these unknowns, with the appropriate algebra. In practice, however, the method does not work because of statistical fluctuations in the data. The equations on which this method rests are very sensitive to these fluctuations, unless the three measurements are taken at very different times (such as immediately following the sample, two hours later, and 10 hours after that). This makes it a difficult, and somewhat dangerous approach to use in the field or in the laboratory.

2.2.4 First Count Factor

The final method discussed in this report is quite different from the others, but is also quite promising [3]. Radon daughters produce both alpha and beta radiation, but regardless of the variations in radon concentration, the ratio of alpha count rate to beta count rate should be constant. In addition, the thoron decay chain is quite similar to the radon chain (see Figure 1 and Figure 2), so the alpha/beta count rate ratios corresponding to the thoron chain should be approximately equal to those of the radon chain. Most contaminants, however, should have different alpha/beta ratios (often the isotope will emit only one or the other), so one can measure the initial alpha and beta count rates, determine the ratio, and compare it to historical values. If the present value differs significantly from historical values, then this is indicative of the presence of a contaminant. If the ratio is much larger, an alpha contaminant is indicated; if it is much smaller, a beta contaminant. Once again, this is not a good quantitative measure for the contaminant, but it would appear to be a good "warning flag" for the presence of contaminants.

This method should work for any ratio of radon-to-thoron backgrounds, and it should work for both long- and short-lived contaminants. Its one blind spot is contaminant isotopes whose alpha/beta count rate ratios do not differ significantly from those of the radon daughters. Although these should be relatively uncommon, plutonium may be one such isotope. Unfortunately, this is an isotope of military interest. For other isotopes, however, this method would appear to be robust.

3. Experimental Validation

This section has two objectives. First, it outlines the technique used in this work for air sampler measurements. This method can be easily transferred to field applications. Second, this section uses the data analysis techniques described in the previous section to analyse a typical set of data in the absence of contaminants. In this way, we can see the strengths and weaknesses of each method.

3.1 Data Acquisition

Most of the air samples in this work were taken for 1 hour, although a smaller number of 30-minute and 15-minute air samples were taken. For the purposes of these analyses, the 60-minute air samples are clearly preferable. The 60-minute samples show noticeably smaller statistical variations, which is useful when trying to extract small signals. A 15-minute sample is probably sufficient if the airborne contaminant concentration is large, but for optimal sensitivity the longer sampling time is advisable.

Measurements on the particulate filters in this work were predominantly done with handheld alpha or beta probes from the RDS-100 system. The best such measurements are made when the probe is as close to the filter as possible. Of course, contact measurements are inadvisable because of the possibility of contaminating the probe. The simplest way to accomplish this in practice (keeping in mind that measurements will take several minutes) is to use some sort of spacer to keep the probe at a constant distance above the filter. In this work, the filter was placed on a horizontal surface (such as a lab bench) and the alpha or beta probe was placed on top of the filter. A Styrofoam spacer kept the probes at a constant distance of 1 cm above the filter throughout the measurement. Obviously, this spacer cannot sit on top of the filter, since it would then absorb the radiation emitted from the filter.

Accurate measurements are important for sensitive results. When the RDS-100 probes are placed above the filters, the count rates rise quickly at first, but take a couple of minutes to reach their ultimate value. Thus, in this work the probe was always allowed to count for at least 2 minutes until the count rates levelled off. At this point, the count rate was observed for a minute or two so as to get a good estimate. At the low count rates observed in this work, fluctuations in count rate can cause inaccurate results if one looks only at instantaneous rates, and not time-averaged ones. For the same reason, all filter measurements must have the instrumental background of the RDS-100 probe subtracted from them. This should be assessed at the time of the measurement by making a measurement of an uncontaminated filter (one which has not been used to capture an air sample).

In this work, alpha and beta count rates were taken every 15 minutes for at least 2 hours. This was done for the purpose of testing the various data analysis strategies. The amount of data collection required in the field will be considerably less, and will be governed by the data analysis techniques to be employed.

The alpha-beta probe data analysed in this work are shown in Figure 3 to Figure 6. Each figure depicts data for a single sampling location. These are all locations at DRDC Ottawa: Room 29 in Building 5, an outdoor location behind Building 5B, and the target room in Building 24. Figure 3 and Figure 6 both show data for Room 29, but the former is for a one-hour sample, while the latter is for a 30-minute sample. Each figure shows four data sets. There are two sets of alpha probe data and two sets of beta probe data, each corresponding to an air sample taken in the morning (starting between 0800 and 0900), and an air sample taken in the afternoon (starting between 1230 and 1330). The data are all normalized to the first measured count rate to facilitate comparisons of the trends in the various data sets. The values of these initial count rates are given in the figure captions.

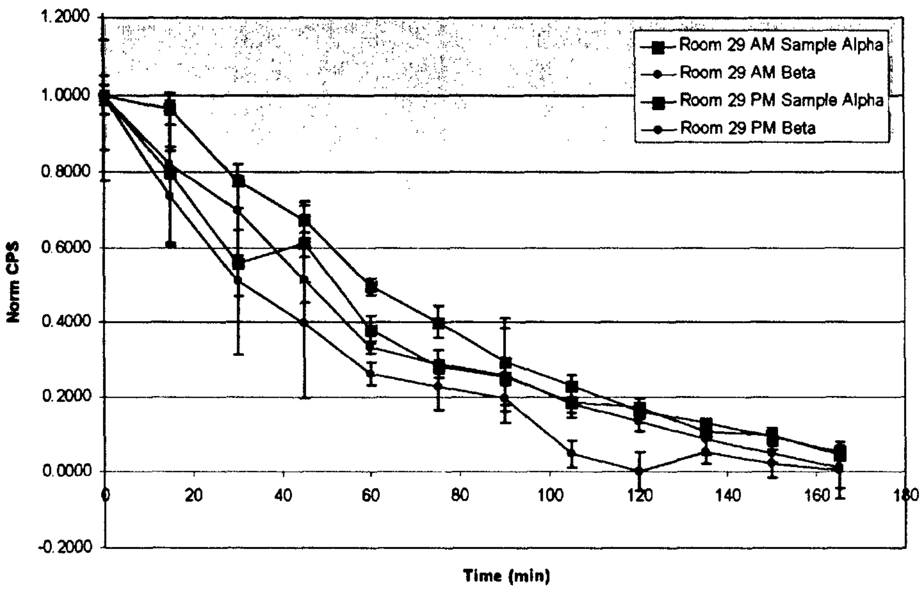

Figure 3. *Alpha and beta probe data for morning and afternoon 1-hour air samples taken in Room 29 of Building 5. The initial count rates for the four data sets are 4.1 cps, 8.1 cps, 2.6 cps, and 5.0 cps (data sets in legend order).*

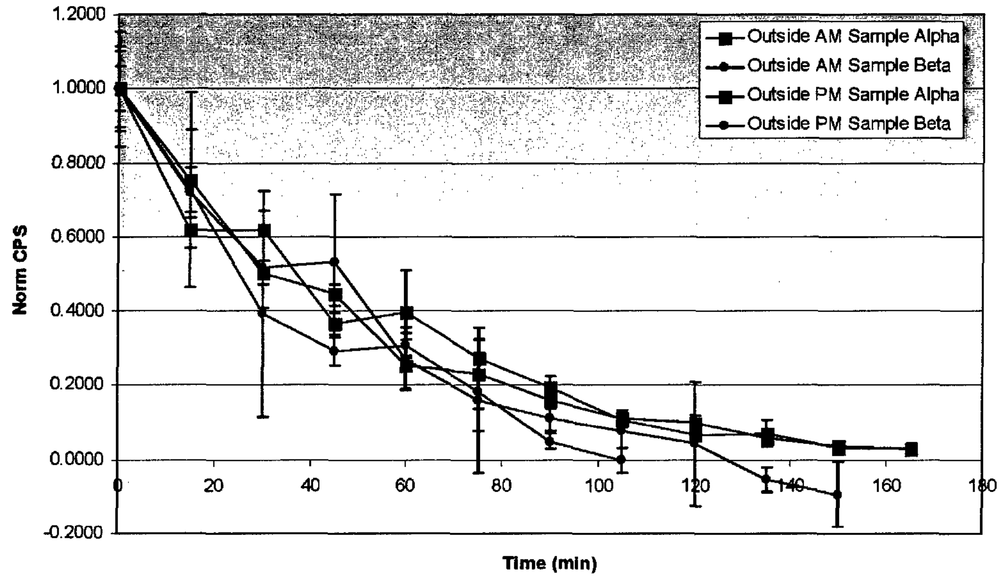

Figure 4. *Alpha and beta probe data for morning and afternoon 1-hour air samples taken outside Building 5B. The initial count rates for the four data sets are 3.8 cps, 4.6 cps, 3.6 cps, and 4.8 cps (data sets in legend order).*

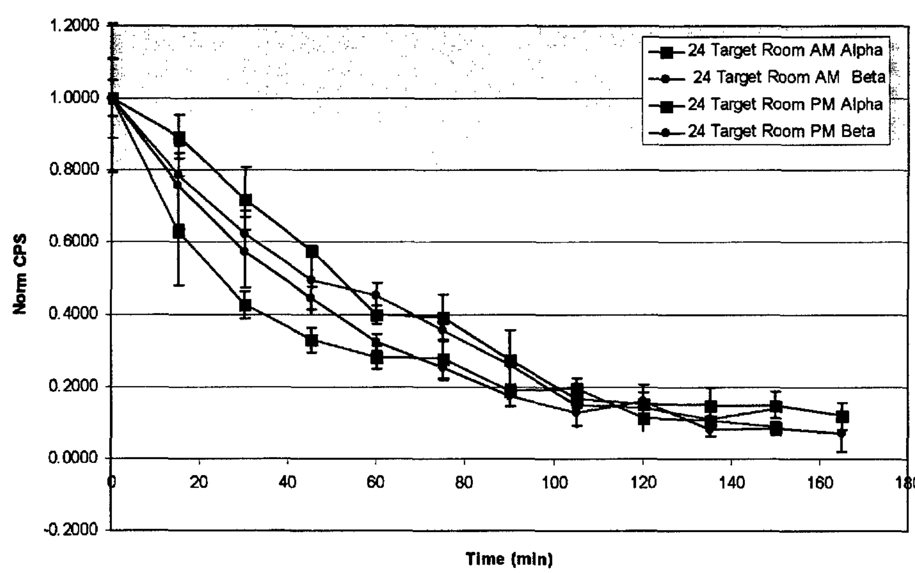

Figure 5. *Alpha and beta probe data for morning and afternoon 1-hour air samples taken in the target room of Building 24. The initial count rates for the four data sets are 5.3 cps, 13.9 cps, 4.5 cps, and 6.9 cps (data sets in legend order).*

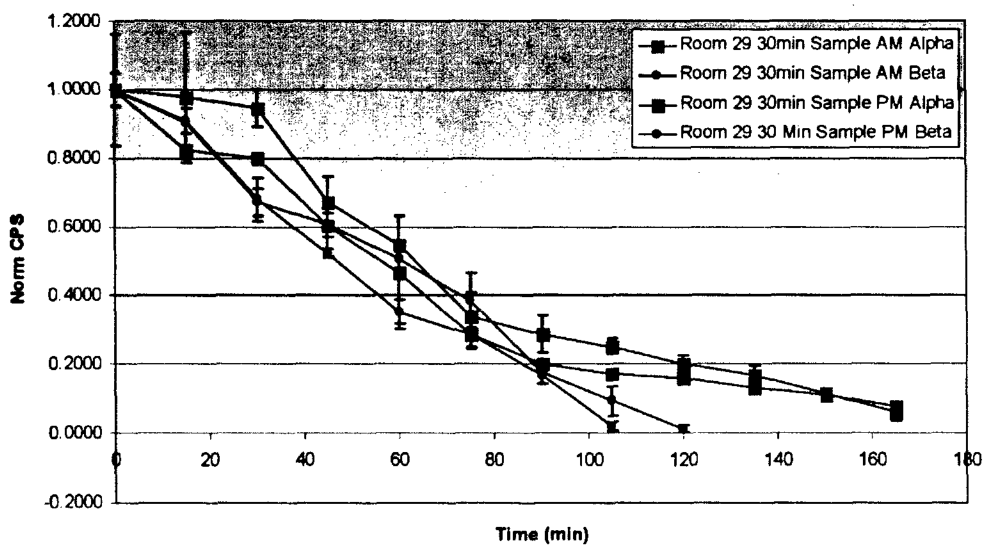

Figure 6. *Alpha and beta probe data for morning and afternoon 30-minute air samples taken in Room 29 of Building 5. The initial count rates for the four data sets are 4.3 cps, 10.8 cps, 4.6 cps, and 8.2 cps (data sets in legend order).*

3.2 Data Analyses

3.2.1 LSC Counting

Most of this section deals with alpha and beta probe data, as depicted in the figures above. However, this sub-section and the next look at data analyses employing other methods. These analyses are given for the sake of completeness, and not because they are recommended for field use.

The first analysis we consider is the use of a liquid scintillation counter (LSC) to analyse the alpha and beta emissions from the particulate filter. LSC measurement is a very effective way to measure these emissions, offering high sensitivity and both alpha and beta spectrometry. However, LSCs (especially those of the kind used in this analysis) are not generally deployable and are not found in any but the most well equipped field laboratories.

Figure 7 shows alpha and beta count rates measured by an LSC from a filter used in a one-hour air sample in Room 29 of Building 5. Instrumental backgrounds have been subtracted for both data sets. Data were taken every 15 minutes for 3 hours. Both data sets fall off smoothly with time, as expected. The fluctuations observed in the alpha and beta probe data are not observed here, indicating that those fluctuations are a consequence of having to make the measurements with a handheld meter, and not a consequence of poor statistics in the decays themselves. The fall-off is approximately

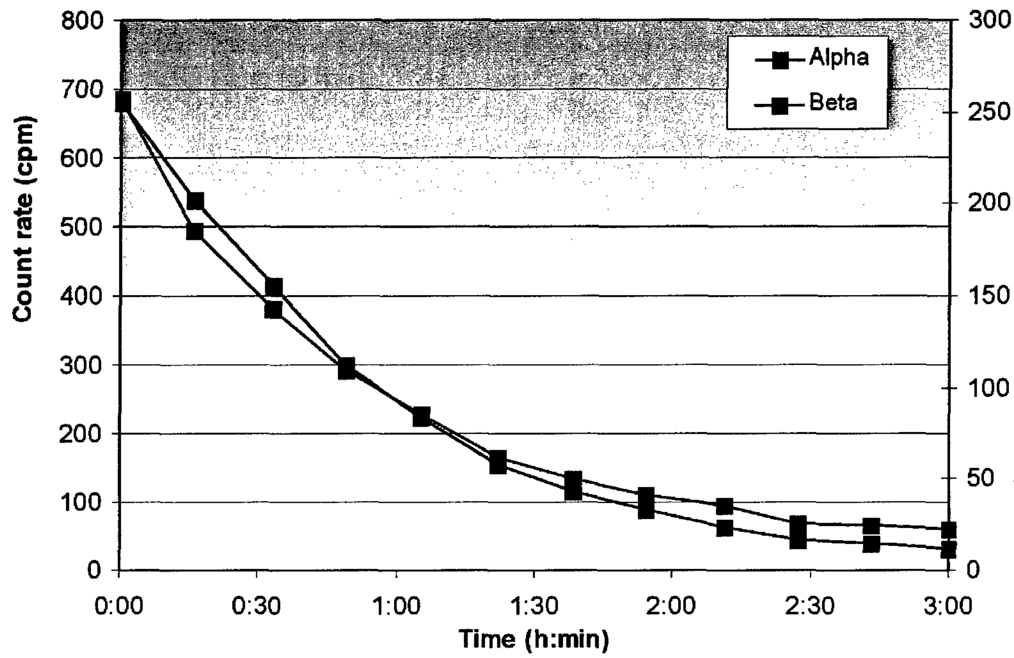

Figure 7. *LSC measurements of an air sample filter from a one-hour sample taken in Room 29 of Building 5. Alpha count rates use the left axis, beta count rates the right. The instrumental background of the LSC has been subtracted from these results.*

exponential, with a half-life of around 35 minutes, indicating that radon daughters dominate this sample. However, the near-constant count rates at non-zero values at the end of the counting period suggest that thoron daughters can also be detected.

Figure 8 is similar, except that a 30-minute air sample is analysed. More important, data are taken over a much longer period to look at the thoron background. Again, after 3 or 4 hours the data decrease at a much slower rate, indicating that thoron daughters are present. Clearly, detecting a signal of this size with an alpha or beta probe would be extremely difficult, given the fluctuations present in the data.

In summary, LSC measurements are highly sensitive and can be used to effectively measure both alpha and beta emissions. Unfortunately, these devices are not generally fieldable, and thus will not be available to the Canadian Forces.

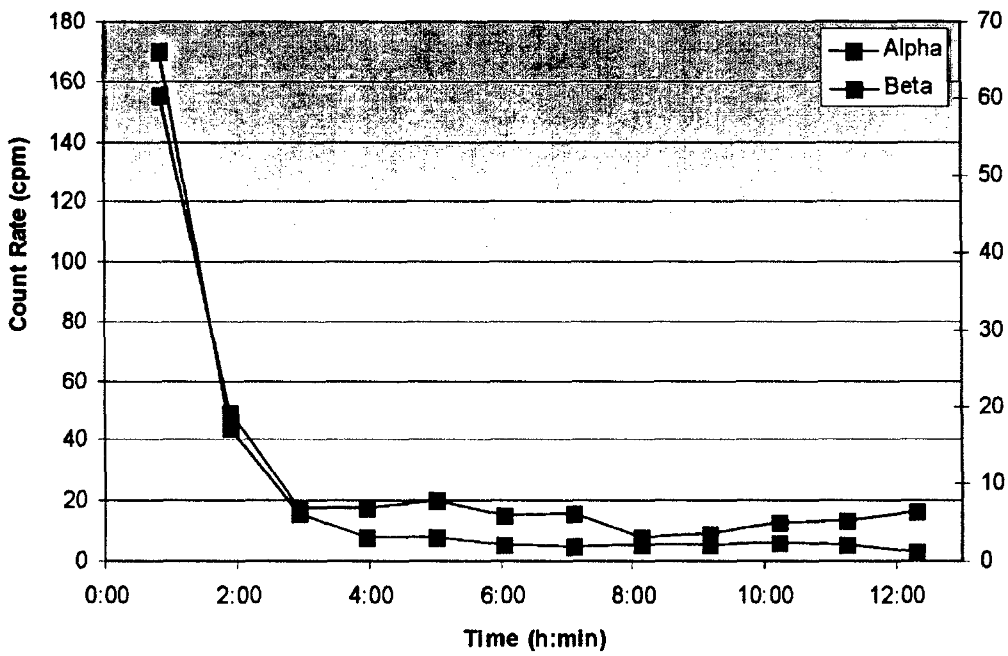

Figure 8. *LSC measurements of an air sample filter from a 30-minute sample taken in Room 29 of Building 5. Alpha count rates use the left axis, beta count rates the right. The instrumental background of the LSC has been subtracted from these results.*

3.2.2 Gamma Spectrometry

Gamma spectrometry is often identified as a field-deployable radiation detection method that can be used for precision measurement and isotopic identification. Gamma spectrometry is of limited utility for air sampling, however, as this section shows.

Figure 9 shows the gamma spectrum measured from an air sampler filter used for a 30-minute sample in Room 29 of Building 5 (blue spectrum). The spectrum was taken for 15 minutes, immediately following the air sample. The spectrum is essentially featureless, except for the peak from potassium-40 at approximately 1450 keV. Since potassium-40 is not likely to be found in the air sample, this is evidence that the raw spectrum exhibits a significant component from the room background. The room background should, therefore, be subtracted from this measurement (this is always good practice). The red spectrum is this room background, also measured for 15 minutes in the same geometry, with an uncontaminated filter. The shape of this spectrum is very similar to that of the original spectrum, although a smaller fraction of the total counts are located at low energies. The difference between these two spectra is shown in green. This spectrum has relatively few counts, indicating that the radon daughters are not prodigious emitters of gamma radiation, and that the gamma radiation is low-energy. The spectrum

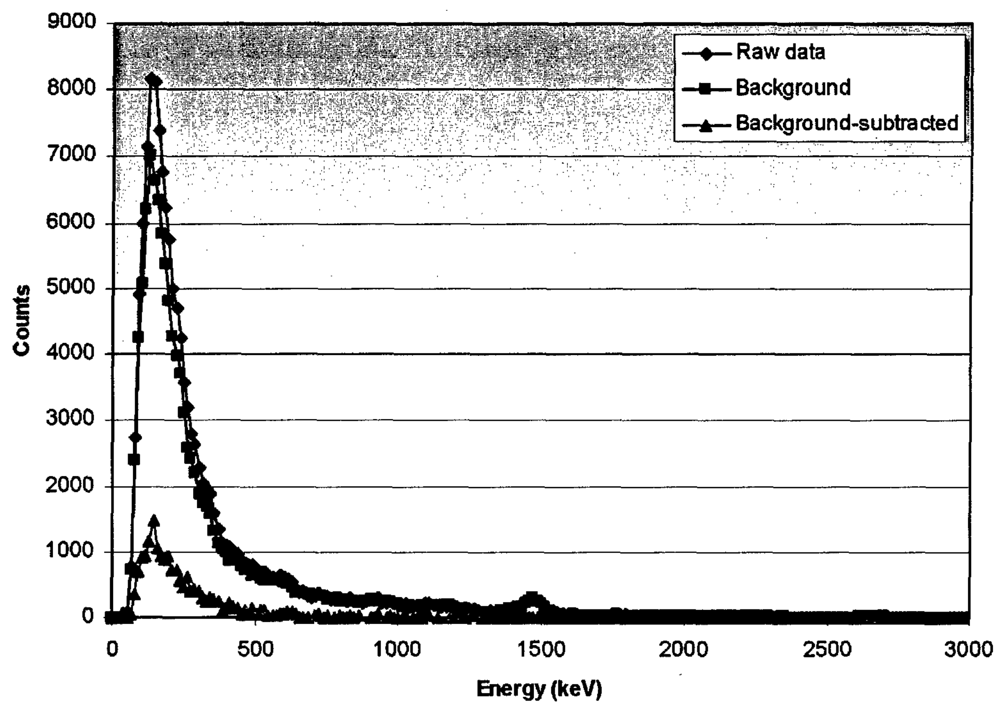

Figure 9. Gamma spectra produced from an air sampler filter. The graph shows unsubtracted data, a background spectrum (taken with an uncontaminated filter) and the difference between the two. This last plot is therefore the gamma signal produced by those radon and thoron daughters caught on the filter.

is also completely featureless. That this spectrum should look like a background spectrum (potassium-40 peak excluded) is expected; after all, it is the radon daughters that produce much of the ambient radioactive background. That being said, the featurelessness of this spectrum is problematic.

How would a soldier use this technique to detect an airborne hazard in the field? Obviously, the soldier would have to recognize the presence of excess counts from a contaminant overlaid on this featureless spectrum. If the contaminant in question emits a small number of (preferably high-energy) gamma rays, then this task may not be too difficult. Cesium-137 or Cobalt-60, for example, may not be difficult to detect against this background. However, a number of potentially hazardous isotopes do not have this pattern of gamma rays. Many have only low-energy emissions, which may be difficult to pick out from the background. Others have several peaks, which end up looking like a smooth spectrum to a sodium iodide detector, because of its low resolution. Finally, some isotopes (including some of the most hazardous ones) have no appreciable gamma emission, or have emissions that are too low in energy to be detected by a gamma spectrometer such as used here. Thus, while gamma spectrometry may be a useful tool for some isotopes, it must be used in combination with other techniques that are

sensitive to alpha and beta emissions. It bears remembering that there are no isotopes for which there are only gamma emissions, so methods that detect alpha or beta emitters will also catch gamma emitters. Gamma spectrometry, of course, does have the advantage of providing isotope identification for those isotopes that can be detected.

3.2.3 Raw Background Subtraction

Perhaps the simplest data analysis scheme would be to determine the background level of radon daughters and subtract this level from all subsequent air samples. As an example of how this might work, initial alpha and beta count rates from 8 air samples are tabulated in Table 1, and histogrammed in Figure 10 and Figure 11. These data demonstrate clearly the inherent variability in radon daughter concentrations with location and time of day. Alpha readings vary by as much as a factor of two over this small data set, and beta readings vary by as much as a factor of three. Thus, any calculated background level must be based on a large number of data points, and not just on a single measurement.

As a test of the background subtraction method, we have proposed the requirement that readings exceeding twice the background level must be investigated, and then applied that test to these data. The "twice background" condition is commonly used for other kinds of radiation measurements. For these data, the condition is not met. This indicates that the condition is somewhat robust, although it is clear that subsequent measurements could easily meet the condition, especially for the beta measurement. Thus, while not foolproof, this analysis is a reasonable first step.

It is also worth noting that the initial count rates for the 30-minute samples are indistinguishable from the initial count rates for the 60-minute samples. This indicates that the radon daughters are reaching equilibrium in 30

Table 1. *Initial alpha and beta count rates from a variety of air samples. All but the last two samples were for 60 minutes. The average rates were 4.1 cps (alpha) and 7.8 cps (beta). None of these samples exceeded twice background, which is why the "Potential Problem" column contains only "No".*

LOCATION	TIME	SERIAL	INITIAL ALPHA RATE	INITIAL BETA RATE	POTENTIAL PROBLEM?
Room 29	AM	1	4.1	8.1	No
Room 29	PM	1	2.6	5.0	No
Outside	AM	1	3.8	4.7	No
Outside	PM	1	3.7	4.8	No
Bldg 24	AM	1	5.3	13.9	No
Bldg 24	PM	1	4.5	6.9	No
Room 29	AM	1 (30 min)	4.3	10.8	No
Room 29	PM	1 (30 min)	3.6	8.2	No

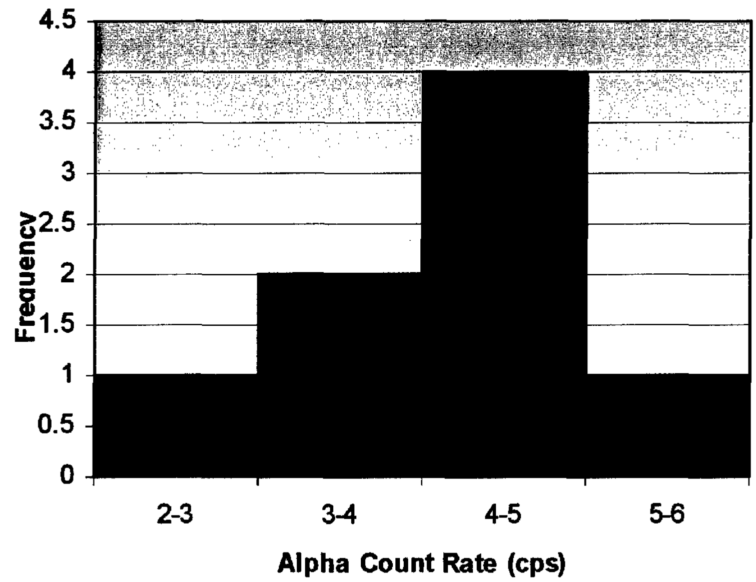

Figure 10. Histogram of initial alpha count rates

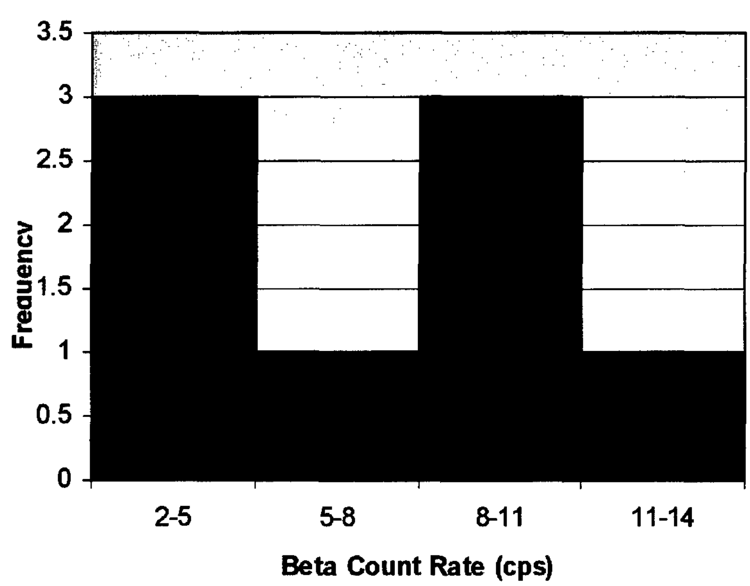

Figure 11. Histogram of initial beta count rates. Note the asymmetry and width of the distribution.

minutes, and that further air sampling is not useful. As suggestive as these data are, however, we believe that this conclusion is based on a statistical fluctuation. With radon daughter half-lives at 35 minutes, equilibrium concentrations can only be reached after about 90 minutes. Once again, these data demonstrate the significant fluctuations in radon daughter concentrations.

It is important to assess each of these data analysis techniques on its sensitivity. While it is not possible to determine a sensitivity level for generic conditions, it is possible to establish such a level for these data as a source of comparison between methods. Based on these data, the sensitivity of this analysis is approximately 4.1 cps alpha and 7.8 cps beta. That is, contaminant concentrations below these levels are as likely to be detected as not because of the "twice background" condition. The significance of these sensitivity levels will be addressed later in this document.

3.2.4 Half-Life Check

Another simple method of data analysis is to calculate the ratio of the initial dose rate to that at some later time, and to compare this ratio to historical values. This is done in Table 2, and depicted graphically in Figure 12 to Figure 15. Recall that radon daughters should produce ratios in excess of unity, whereas long-lived contaminants should have ratios equal to unity. Based on this qualitative criterion, the 60-minute ratios are superior, since the radon daughters produce ratios that are more distinct from those of long-lived contaminants.

Once again, we must choose a criterion with which to flag suspect events. The figures suggest that the distributions are peaked in the centre and relatively tight. This permits us to set a criterion based on whether the measurement is within some number of standard deviations from the mean. For the 30-minute ratios, we choose one standard deviation. This is not expected to be a robust test (even a Gaussian distribution would fail this test 16% of the time[3]). However, the distribution is too wide and too close to unity to permit a more stringent test. For the 60-minute ratios, we choose two standard deviations. This should be far more robust (2% failure rate by chance).

Using these criteria, there are two potential problems, one in the 30-minute alpha ratios and one in the 30-minute beta ratios. These are obviously false positives, since there are no contaminants present in these data. There are no false alarms in the 60-minute ratios.

[3] Sixty-eight percent of a Gaussian distribution lies within one standard deviation of the mean. In our case, we would flag only half of the outliers; very large ratios would be an indication of a very short-lived nuclide, an unlikely occurrence.

Table 2. *Tests of the "Half-Life Check" method of data analysis. Shown are the ratios of the initial count rate to that at either 30 minutes (for the "(30)" data sets) or 60 minutes (for the "(60)" data sets). As expected, the 60-minute analysis is more robust.*

LOCATION	TIME	SERIAL	ALPHA (30)	BETA (30)	ALPHA (60)	BETA (60)	PROBLEM?
Rm 29	AM	1	1.29	1.43	2.02	3.00	No
Rm 29	AM	2	1.43	1.60	2.40	2.85	No
Rm 29	PM	1	1.80	1.96	2.63	3.81	No
Rm 29	PM	2	1.30	1.85	2.85	3.25	No
Outside	AM	1	1.99	1.93	3.91	3.71	No
Outside	AM	2	1.69	1.35	3.27	4.48	Beta (30)
Outside	PM	1	1.62	2.54	2.53	3.26	No
Outside	PM	2	1.68	2.49	2.26	3.97	No
Bldg 24	AM	1	1.39	1.75	2.51	3.10	No
Bldg 24	AM	2	1.55	1.71	2.28	3.02	No
Bldg 24	PM	1	2.35	1.60	3.55	2.21	No
Bldg 24	PM	2	1.92	1.59	2.29	2.21	No
Rm 29	AM	1 (30 min)	1.06	1.49	1.82	1.97	Alpha (30)
Rm 29	AM	2 (30 min)	1.46	1.50	2.90	2.36	No
Rm 29	PM	1 (30 min)	1.25	1.47	2.15	2.84	No
Rm 29	PM	2 (30 min)	1.36	1.74	2.89	3.18	No

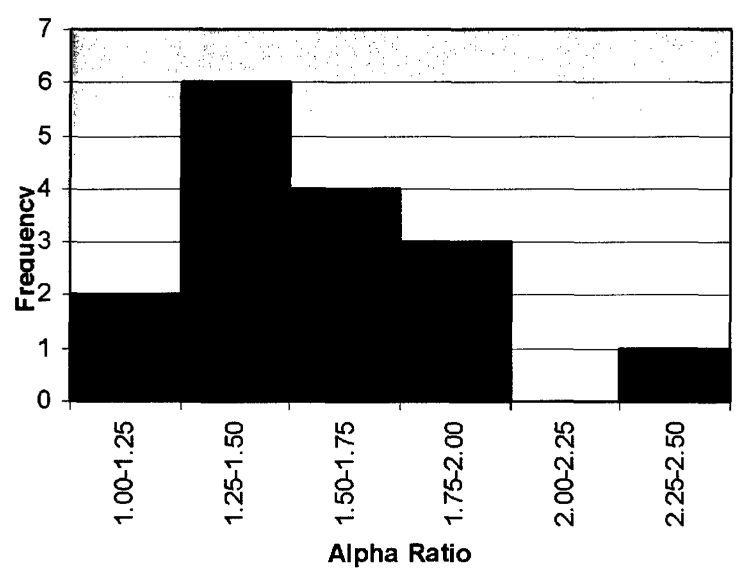

Figure 12. *Histogram of the ratio of the initial alpha count rate to that at 30 minutes. The mean and standard deviation of the distribution are 1.57 and 0.33, respectively.*

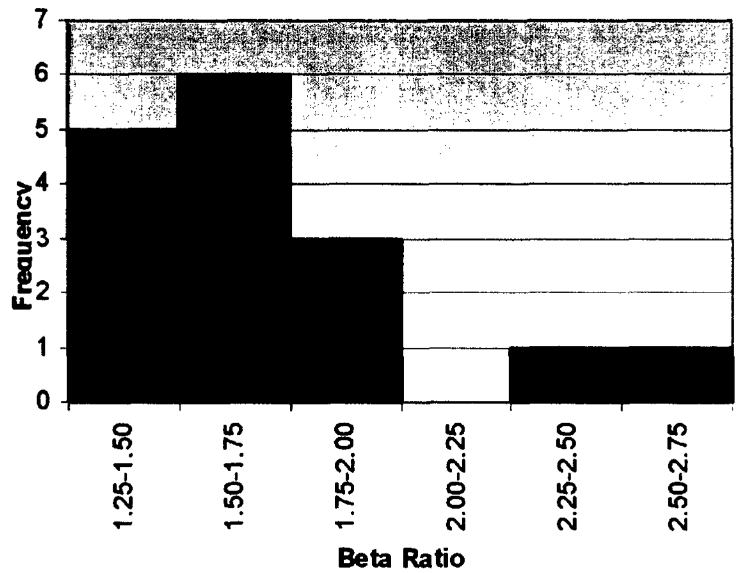

Figure 13. *Histogram of the ratio of the initial beta count rate to that at 30 minutes. The mean and standard deviation of the distribution are 1.75 and 0.35 respectively.*

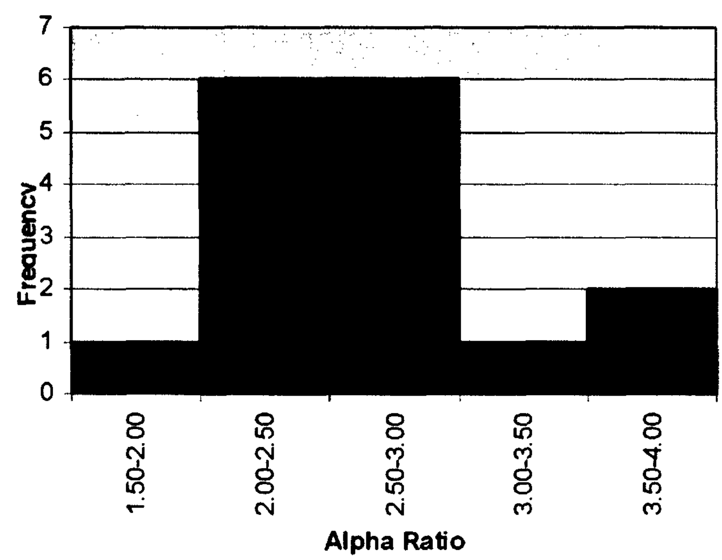

Figure 14. *Histogram of the ratio of the initial alpha count rate to that at 60 minutes. The mean and standard deviation of the distribution are 2.64 and 0.56 respectively.*

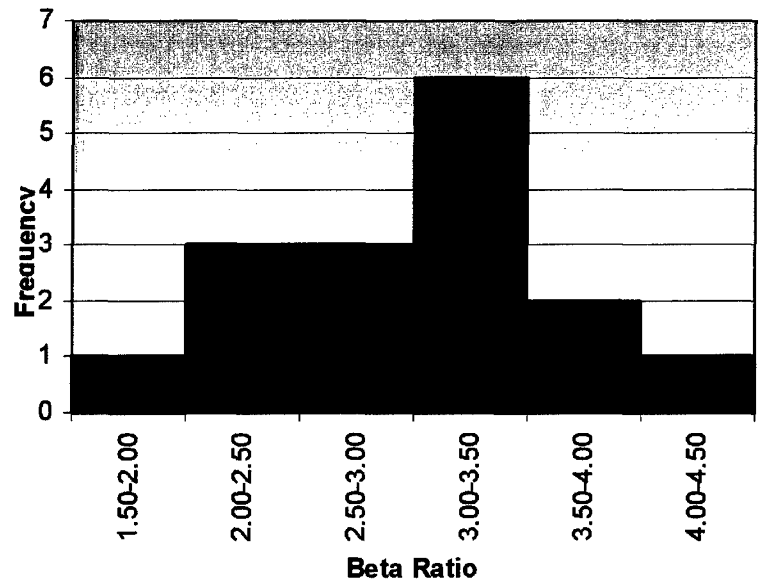

Figure 15. Histogram of the ratio of the initial beta count rate to that at 60 minutes. The mean and standard deviation of the distribution are 3.08 and 0.69 respectively.

Based on these criteria and the average count rates shown in the previous section, it is possible to set a sensitivity level for this analysis. For the 30-minute ratios, the levels are 3.6 cps alpha and 3.9 cps beta. For the 60-minutes ratios, the levels are 3.3 cps alpha and 5.0 cps beta. While these are approximately equal, it is important to remember that these levels are expected to produce far more false positives for the 30-minute ratios than for the 60-minute ratios.

3.2.5 Multi-Point Calculation

A more computationally complex method of data analysis is the multi-point calculation. In this work, we have used measurements from 0, 30, and 60 minutes to calculate the contaminant count rate. From past experience, we know that these data points are taken too close together to produce robust results, but we use these particular data points nonetheless in the interest of field expediency.

Table 3 shows the results of this analysis. Residual (contaminant) alpha and beta count rates are given as a fraction of the initial count rate. Histograms of these results are shown in Figure 16 and Figure 17. As expected, these results show large fluctuations. The alpha histogram, in particular, does not have the appearance of a well-defined distribution. We observe four false positives (positive contaminant count rates) in the alpha data, and two false alarms in the beta data.

Table 3. *Tests of the "Multi-Point Calculation" method of data analysis, using count rates from 0, 30, and 60 minutes. Shown are the calculated contaminant count rates, as a ratio of the initial count rate.*

LOCATION	TIME	SERIAL	ALPHA	BETA	PROBLEM?
Rm 29	AM	1	-3.86	0.16	Beta
Rm 29	AM	2	-2.20	-1.03	No
Rm 29	PM	1	-0.32	-0.89	No
Rm 29	PM	2	-0.37	-0.55	No
Outside	AM	1	1.59	-0.15	Alpha
Outside	AM	2	-0.41	-1.55	No
Outside	PM	1	-3.17	-2.17	No
Outside	PM	2	-3.35	-0.63	No
Bldg 24	AM	1	-1.30	0.98	Beta
Bldg 24	AM	2	-2.11	-0.39	No
Bldg 24	PM	1	1.11	-3.03	Alpha
Bldg 24	PM	2	-2.01	-3.12	No
Rm 29	AM	1 (30 min)	-4.48	-7.53	No
Rm 29	AM	2 (30 min)	0.66	-5.49	Alpha
Rm 29	PM	1 (30 min)	-3.02	-3.48	No
Rm 29	PM	2 (30 min)	0.33	-2.39	Alpha

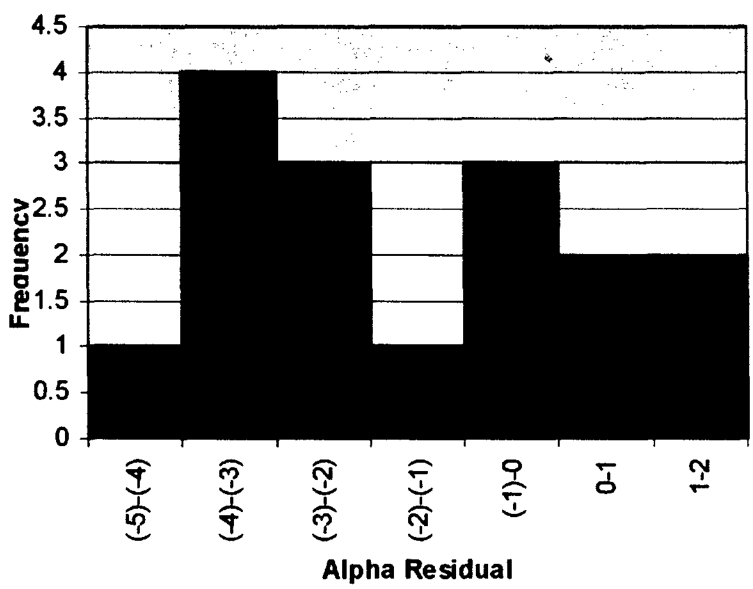

Figure 16. *Histogram of residual alpha count rates (attributable to contaminants), as calculated by the Multi-Point Calculation. The rates are given as a ratio of the initial count rate. Values greater than zero would indicate a contaminant.*

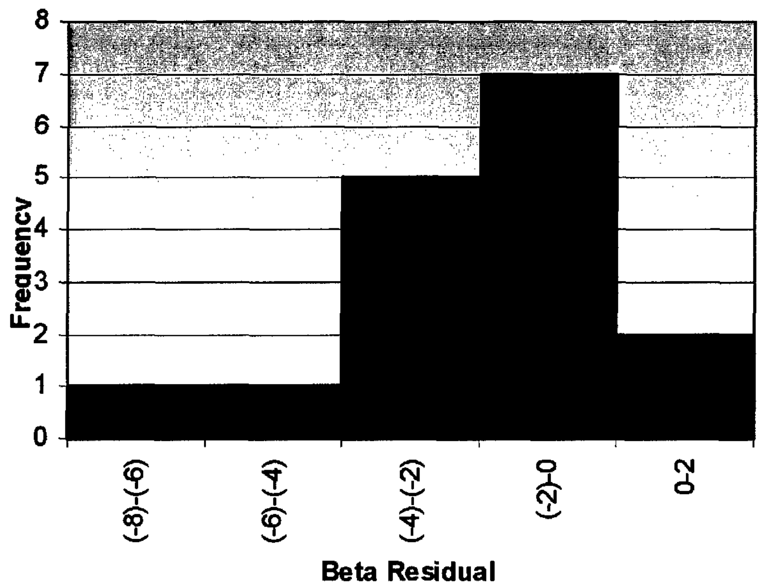

Figure 17. *Histogram of residual beta count rates (attributable to contaminants) as calculated by the Multi-Point Calculation. The rates are given as a fraction of the initial count rate. Values greater than zero correspond to non-zero contaminants.*

If we make the test more stringent by requiring that the contaminant count rate must be one standard deviation larger than the mean, this eliminates one false alpha warning, and one false beta warning (the alpha mean and standard deviation are –1.43 and 1.87, respectively, while the corresponding numbers for the beta distribution are –1.95 and 2.21). If we make the test even more stringent by stipulating that the results must be two standard deviations larger than the mean, we eliminate all of the false positives. However, at these levels, the sensitivity level is 7.7 cps alpha and 17.2 cps beta, twice as high as for any of the other methods.

3.2.6 First Count Factor

Another very simple analysis is the first count factor. This ratio of initial alpha rate to initial beta rate should be constant, regardless of fluctuations in radon or thoron concentration. These ratios are tabulated in Table 4 and the ratios are histogrammed in Figure 18. The figure shows that the distribution does not have the bell curve appearance that one would like to see. This may be an issue of insufficient statistics. The good news is that all of the data points are within two standard deviations of the mean. Using this as the criterion for additional analysis, the sensitivity of this method is 2.0 cps alpha and 7.8 cps beta. If you use the reciprocal of the first count factor, the same criterion will give a beta sensitivity level of 4.0 cps, but this improvement is not worth the added complication of a second ratio.

Table 4. *Tests of the "First Count Factor" method of data analysis. The mean and standard deviation of the distribution are 0.57 and 0.14, respectively.*

LOCATION	TIME	SERIAL	FIRST COUNT FACTOR	PROBLEM?
Rm 29	AM	1	0.50	No
Rm 29	AM	2	0.59	No
Rm 29	PM	1	0.53	No
Rm 29	PM	2	0.57	No
Outside	AM	1	0.81	No
Outside	AM	2	0.85	No
Outside	PM	1	0.76	No
Outside	PM	2	0.65	No
Bldg 24	AM	1	0.38	No
Bldg 24	AM	2	0.45	No
Bldg 24	PM	1	0.65	No
Bldg 24	PM	2	0.52	No
Rm 29	AM	1 (30 min)	0.40	No
Rm 29	AM	2 (30 min)	0.43	No
Rm 29	PM	1 (30 min)	0.56	No
Rm 29	PM	2 (30 min)	0.51	No

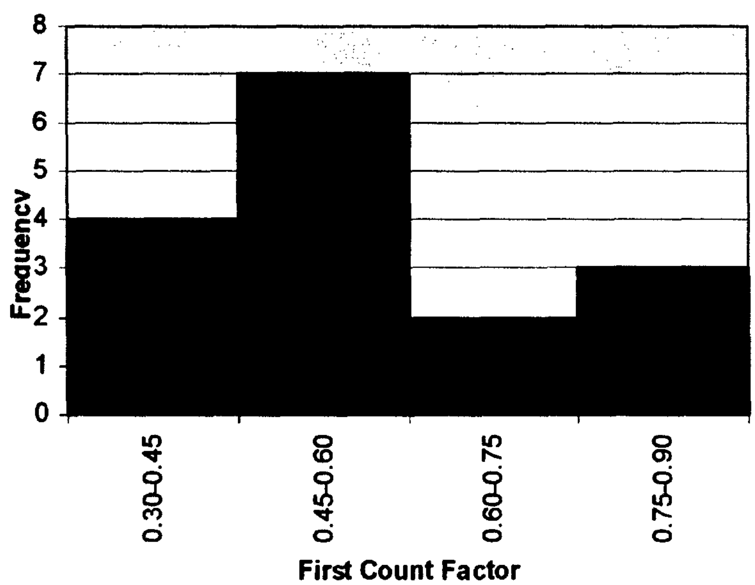

Figure 18. *Histogram of the first count factor. Although the distribution does not look very tight, all values are within 2 standard deviations of the average.*

4. Recommendations

The preceding sections have described and tested a number of potential data analysis techniques. In the process, their advantages and disadvantages have become clear. These are summarized in Table 5. It is clear that some methods should be avoided. In particular, the use of liquid scintillation counting is ruled out because of the complexity of the equipment, and the Multi-Point Calculation is ruled out for a number of reasons. However, the remaining methods have certain advantages that together make a reasonable approach to data analysis. Specifically, the first count factor should be calculated immediately. Similarly, a raw background subtraction should be performed. Together, these methods are simple, fast, and applicable to all isotopes. Gamma spectrometry can also be performed on the filter, if this equipment is available. This could be quite valuable if the contaminant is a gamma emitter. Confirmation of the initial result can be gained from a half-life check once an hour has elapsed. Note however, that protective actions should be taken immediately if indicated by the first analysis, without waiting for confirmation.

Another clear lesson from this work regards the value of baseline measurements. None of these methods can be used if baseline measurements have not been taken beforehand. Furthermore, such baseline study does not consist of a single measurement. Instead, a series of measurements must be taken at the operating location(s) at different times of day. Only in this way can a suitable dataset be established to compare with later measurements.

Table 5. *Data analysis techniques for air samples, with their associated advantages and limitations.*

METHOD	ADVANTAGES	LIMITATIONS
Liquid Scintillation Counting	- high precision with isotopic ID	- not fieldable - takes a long time
Gamma Spectrometry	- isotopic ID	- insensitive to alpha, beta, and low-energy gamma
Raw Background	- simple and fast	- considerable variability
Half-Life Check	- simple and somewhat robust	- takes > 1h for result - insensitive to short-lived isotopes
Multi-Point Calculation		- poor sensitivity - takes > 2h for good result - not robust - insensitive to short-lived isotopes
First Count Factor	- sensitive - simple and fast - robust	- distribution not tight - insensitive to alpha-beta emitters

Annex A details a draft protocol for the analysis of field air sampling data, drawing on the above recommendations. In the interest of field expediency, these methods are modified slightly from the main body of the report to remove the need for calculation of means and standard deviations. The Annex also contains an example analysis using real air sampling data. This example also highlights the importance of baseline measurements.

The ultimate question to be answered by this study is "What is the sensitivity of the air sampler and the RDS-100 to airborne radionuclides?" In this work, we have seen that the various analysis techniques have sensitivities ranging from 2 to 4 cps for alphas and 5 to 8 cps for betas. These sensitivities will vary depending on local conditions, but can be used to get an estimate of the system sensitivity. For these calculations, therefore, we take the minimum detectable alpha count rate to be 3 cps and the minimum detectable beta count rate to be 6 cps.

In Annex B, we determine the efficiency factors for the RDS-100 alpha and beta probes for 8 selected isotopes. Combining the above count rates with these efficiencies, we derive the minimum detectable activities in Table 6. This is the minimum detectable activity of the isotope that could be found on the filter despite the radon background. For isotopes that could be detected by both the alpha and beta probes, the lower activity is used.

In order to determine the airborne concentration to which these levels correspond, we merely divide the activity by the volume sampled. Assuming a 60-minute air sample and a sampling rate of 5.75 m^3/h (the average value for this work), the concentrations in column 3 of the table are determined. These concentrations can then be converted to committed dose rates with the use of an inhalation dose coefficient. There are many sources of these coefficients; we have used the coefficients from the US nuclear regulatory document FGR-11. They are shown in column 4 of the table. The absolute values of these coefficients are not terribly important for this work, since we are more interested in the trends that are produced.

Table 6. *The sensitivity of the air sampler and RDS-100 to airborne radiological hazards. For beta emitting isotopes, the sensitivity level is reasonable. For alpha emitters, the committed dose rates are quite large.*

ISOTOPE	MINIMUM DETECTABLE ACTIVITY (Bq)	AIRBORNE CONCENTRATION (Bq/m^3)	INHALATION DOSE COEFFICIENT (Sv/Bq)	COMMITTED DOSE RATE (μSv/h)
C-14	81	14.2	5.64E-10	0.0120
Tc-99	22	3.8	2.25E-09	0.0128
Cl-36	9.7	1.68	5.93E-09	0.0150
Sr-90	5.6	0.97	3.51E-07	0.51
Am-241	16.2	2.8	1.20E-04	510
EU	19.8	3.4	3.58E-05	185
DU	12.9	2.2	3.20E-05	107
Th-232	2.0	0.34	4.43E-04	230

When the airborne concentration is multiplied by an inhalation dose coefficient and a breathing rate (we have used 1.5 m^3/h, corresponding to moderate physical exertion), the committed dose rate in the final column of Table 6 is obtained. This dose rate is the minimum detectable dose rate using the air sampler and the data analysis techniques suggested here. Once again, it is not the values of these dose rates that are so important, but rather the overall trends. These are quite simple. For the beta-emitting nuclides we have studied (all of which are relatively low in atomic mass), the committed dose rates are low, often at levels comparable to other natural radioactive backgrounds. Thus, for a hazard involving such an isotope the air sampler can detect levels below levels of health concern. However, for the heavier alpha-emitting transuranic elements, the committed dose rate exceeds 100 μSv/h, well above the NATO and civilian hazard levels (which are around 1 μSv/h). Thus, airborne hazards involving transuranic isotopes could be well above conventional hazard levels and yet still be undetectable by this system. This is the key limitation of this kind of system, and underlines the necessity for the air monitor system also purchased by the 2199 project.

To summarize, the air sampler and the RDS-100 system can be used effectively to warn troops of a wide variety of beta- and gamma-emitting airborne hazards, with the data analysis techniques described in this document. However, for airborne hazards involving alpha-emitting transuranic elements, this system is incapable of providing warnings at appropriate levels. For such a hazard, one must use the alpha air monitor also procured by the 00002199 project.

5. References

1. Directorate of Nuclear Biological and Chemical Defence (15 November 1998). Project Charter for Canadian Forces Nuclear Detection Identification and Dosimetry Project, Version 1.0. Department of National Defence.

2. Haslip, D.S. and Estan, D. (March 2001). Radiological Air Sampling for the Canadian Forces (DREO TM 2001-033). Defence Research Establishment Ottawa.

3. Moe, H.J. and Vallario E.J. (June 1992). Operational Health Physics Training, Section 14 (ANL-88-26). Argonne National Laboratories.

Annex A. Draft Protocol for Field Air Sampling

Section B.1 of this Annex describes the air sampling protocol developed as a result of this work. Section B.2 gives a concrete example of how this analysis works, using data analysed earlier in this document.

A.1 The Protocol

1. In the event of a radiological hazard, interpretation of air sampler data will be exceedingly difficult unless many air samples have already been taken and measured at that operating location. Air samples should be collected and analysed regularly according to the protocol below, from the time the sampler is deployed until the end of the mission. Samples should be taken at a number of different locations, and at different times of day. The results of all of these "historical" samples must be recorded in a single location to facilitate later analysis.

2. Use Air Sampler SOPs to take an air sample.
   a. Use a pencil to indicate a small "X" on the side of the filter paper facing outwards. This is the side of the filter paper where the particulates will collect, and this is the side that you will measure in subsequent steps.
   b. The flow rate should be approximately 100 litres per minute. The sample should be taken for at least 30 minutes, although 60 minutes is desirable. For best results, sampling times and volumes should be kept constant.

3. Remove the filter from the air sampler and place it on a flat surface with the side with the "X" facing up. Measurement of this sample should begin as soon as possible (within minutes) following the completion of the sample collection.

4. Using the RDS-100 with the alpha probe, measure the alpha count rate of the air sampler filter. The probe should be 1 cm above the surface of the filter, and the probe should be left in this position for approximately 2 minutes to allow the count rate to stabilize.
   a. Since it is very difficult to hold the probe at such a small distance above the filter for an extended period of time, the use of a spacer or jig is strongly recommended. The spacer could, for example, consist of a 1-cm thick piece of wood or Styrofoam with a hole in the middle that is at least as large as the air sampler filter. The spacer and filter are then placed on a table with the filter in the hole in the spacer, and the probe is placed on top of the spacer. Additional support for the handle may be required if the probe begins to tip over.
   b. After a two-minute stabilization period, the average count rate should be noted. Call this count rate AU0.
   c. Determine a background rate by repeating this measurement with a clean filter (one that has not been used in the air sampler). For expediency, this step can be performed earlier in the process (such as while the air sampler is running). Call this background rate AX.

   d. Subtract the background rate from the count rate AU0 to get the rate A0=AU0-AX.

5. Repeat step 4 with the RDS-100 and the beta probe, in order to determine the beta count rate of the air sampler filter BU0. Once again, the probe should be 1 cm above the surface of the filter and should be left in this position for 2 minutes for stabilization. A spacer or jig is, again, strongly recommended. The background rate BX for the beta probe must be determined with a clean filter, since it will be different from the alpha probe background. Call the background-subtracted count rate B0=BU0-BX.

6. Compare these values of A0 and B0 to historical values of A0 and B0. Some fluctuation is normal. However, if the present value of either A0 or B0 is greater than all of the historical values, then it is possible that there is a radiological contaminant in the air. Respiratory protection may be required, and further analyses of this sample should be given priority.

7. Take the ratio of the alpha count rate to the beta count rate, and call this ratio F0=A0/B0. Compare this value of F0 to historical values of F0. Some fluctuation is normal. However, if the present value of F0 is greater than all historical values or smaller than all historical values, then it is possible that there is a radiological contaminant in the air. Respiratory protection may be required, and further analyses should be given priority.
   a. If the ratio is anomalously large, then this is indicative of an alpha hazard. If the ratio is anomalously small, then this is indicative of a beta hazard.
   b. If both this test and the test in step 6 indicate a hazard, then it is likely that a hazard exists. Respiratory protection should be used and further analyses should be completed with priority.

8. Repeat steps 4 and 5 to obtain a second set of alpha and beta count rates. These measurements should be made 60 minutes following the first set of measurements (in which case the rates are called A60 and B60). The background rates AX and BX do not need to be re-measured, but they do need to be subtracted from the measured rates, so A60=AU60-AX for example)

9. Take the ratio of the initial alpha count rate to the alpha count rate after 1 hour, and call this ratio RA=A0/A60. Also determine the ratio RB=B0/B60.

10. Compare these values of RA and RB to historical values of RA and RB. Some fluctuation is normal. However, if the present value of either RA or RB is greater than all historical values or smaller than all historical values, then it is possible that there is a radiological contaminant in the air. In addition, a radiological contaminant may be present if either ratio gets close to 1.0, regardless of the range of historical values. Respiratory protection may be required and further analyses should be given priority.
    a. If the ratio is anomalously large, this is indicative of a short-lived contaminant, which is generally less serious. However, analyses must be completed quickly to determine the nature of the contaminant before it

disappears. If the ratio is anomalously small, this is indicative of a long-lived contaminant, which is normally more hazardous.

b. If this test and either of the preceding tests indicate the presence of a hazard, then it is likely that a hazard exists. Respiratory protection should be used, and further analyses should be completed with priority. It is not necessary for all three tests to give positive results. In fact, a positive result on only one test may be indicative of a problem.

11. A gamma-ray spectrum of the filter should also be taken, especially if one or more of the previous tests indicated the presence of a hazard. A 15-minute spectrum should be taken with the GR-135. The same spacer described above can be used for this measurement as well. A 15-minute background spectrum should also be collected in the same way, with a clean filter. The background spectrum should be subtracted from the spectrum of the air sampler filter. If the appearance of this background-subtracted spectrum differs significantly from that of other background-subtracted spectra of historical air samples, then this may be indicative of an aerosol hazard.

A.2 An Example

Table 7 shows example data with which the protocol can be illustrated. The sample data are taken from the data used in this report. Six samples are shown, each with their values of A0, B0, F0, A60, B60, RA, and RB as described above. Five samples are used as an (inadequate) historical collection. Maximum and minimum values for this historical data set are also given. Finally, data for a sixth air sample are shown. This will be used as a test case in the discussion that follows.

The sixth air sample is collected, and the initial alpha and beta count rates are determined. The background-subtracted rates are A0=4.48 cps and B0=6.92 cps. Both of these are within the range of values in the historical data set, so no contaminant is suspected. The ratio of A0/B0 is equal to F0=0.65. This is also within the range of historical values, so no hazard is indicated.

After an hour, the alpha and beta count rates are measured again, and the background-subtracted rates are A60=1.26 cps and B0=3.13 cps. The ratio of the initial alpha count rate to this alpha count rate is RA=A0/A60=3.55, and the corresponding beta ratio is RB=B0/B60=2.21. The ratio RA is within the range of historical values, so no hazard is indicated. However, the ratio RB is smaller than all previously observed values, so an aerosol hazard is possible. The hazard indicated by this result is a beta-emitter (because the anomaly is with RB and not RA), and it is long-lived (because RB is smaller than normal). Further follow-up is required, despite the fact that the other tests did not indicate a problem. However, the fact that B0 was not anomalously large and that F0 was not anomalously low (compared to historical values) suggests that this RB result is a false alarm.

In fact, there is no aerosol hazard present in these real-life data. This example serves to indicate the potential for false alarms in this system, especially when the historical

data set is too small. It is clear that analysis of these data without a large amount of historical data is difficult and subject to considerable uncertainty. Thus, it is incumbent on the CF member responsible for air sampling to collect a large number of air samples as soon as possible in the rotation so that (a) he or she is familiar with the equipment, the measurement techniques, and the analysis methods; and (b) that a large collection of historical data is available when an air sample analysis is required.

In this example, follow-up is required. A gamma spectrum of the filter should be taken. This can be a quick indication of a hazard, although there is no guarantee that the hazard isotope would show up in a gamma spectrum. In this example, the gamma analysis would show no contaminant. A second air sample should also be immediately undertaken and analysed to see if these results are reproducible. Respiratory protection is probably not necessary; the level of contaminant contributes less than 6 cps to the air sampler filter (since the total initial beta count rate was 6.92 cps), which means that the inhaled dose rate is less than 0.5 μSv/h (see the rows of Table 6 corresponding to beta emitters, which were based on a beta count rate of 6 cps). Higher headquarters should also be notified of the potential problem. Once it is determined that this was a false alarm, the sixth data set can be added to the historical data set, thus changing the averages and standard deviations.

Table 7. *Example data to illustrate the air sampling protocol outlined in this section. Five samples comprise a (limited) historical data set. The sixth sample is the test case.*

SAMPLE	A0 (cps)	B0 (cps)	F0	A60 (cps)	B60 (cps)	RA	RB
1	4.06	8.07	0.50	2.01	2.69	2.02	3.00
2	2.63	5.00	0.53	1.00	1.31	2.63	3.81
3	3.76	4.65	0.81	0.96	1.26	3.91	3.71
4	3.65	4.80	0.76	1.45	1.47	2.53	3.26
5	5.27	13.88	0.38	2.10	4.48	2.51	3.10
Max Value	5.27	13.88	0.81			3.91	3.81
Min Value	2.63	4.65	0.38			2.02	3.00
6	4.48	6.92	0.65	1.26	3.13	3.55	2.21
Hazard Indication?	No	No	No			No	Yes

Annex B. Sensitivity of the RDS-100 Probe

In order to correctly interpret air sampler measurements taken with an alpha or beta probe, the efficiency of the probe must be known. That is, one must have a factor that converts count rate into activity. This annex presents some efficiency data corresponding to selected isotopes for the alpha and beta probe that are used with the RDS-100 system.

The experimental procedure was simple. Area sources of C-14, Cl-36, Sr-90, Tc-99, Th-232, U-235, U-238, and Am-241 were measured with both the alpha and beta probe of the RDS-100 system. Measurements were made with probe-source separations of 1 cm, 2 cm, and 5 cm. Combined with the known activity levels of these sources, we can extract efficiency values.

Examples of these data are shown in Figure 19 and Figure 20. They show the significant advantage of making such measurements at small probe-source distances, particularly for alpha sources. This is why all of the air sample measurements were made with probe-filter distances of 1 cm (ensured by the Styrofoam spacer).

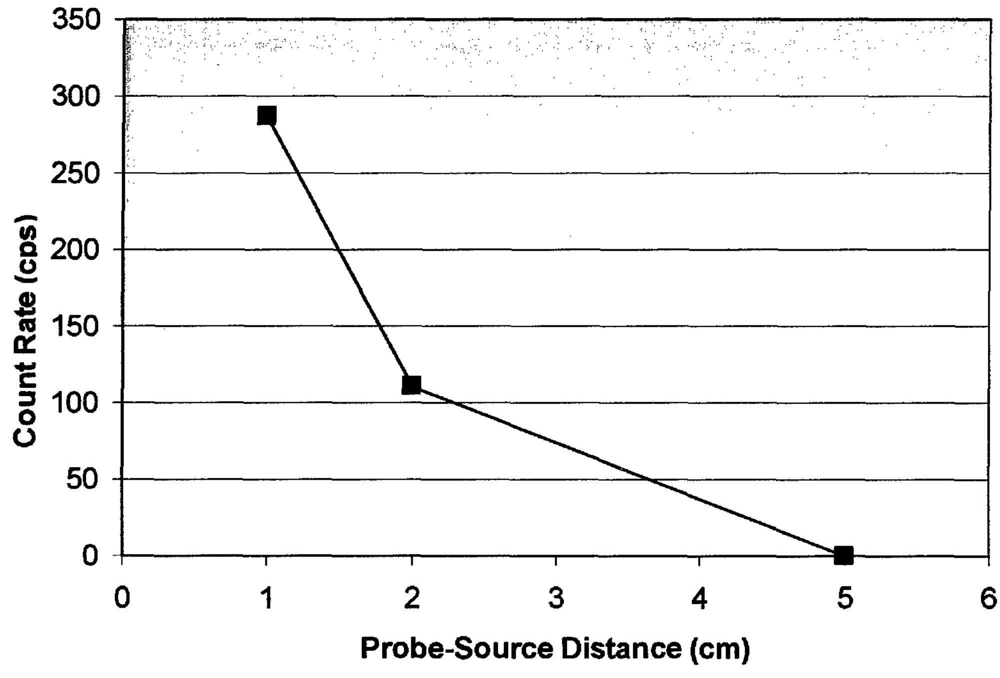

Figure 19. *Alpha probe count rate as a function of distance from an Am-241 source. Note the large increase in dose rate as the probe approaches to 1 cm.*

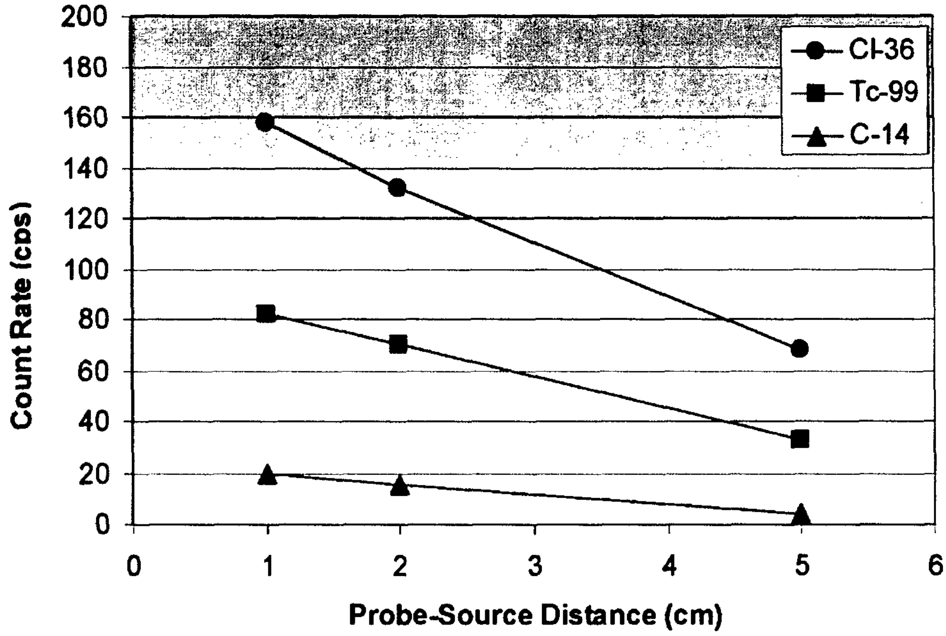

Figure 20. Beta probe count rate as a function of distance from several beta sources. Note the advantage of making measurements at small distances.

The results of these tests are summarized in Table 8. The efficiencies of the alpha and beta probes to each of the eight isotopes are tabulated. One can see that the alpha probe is completely insensitive to the beta-emitting isotopes, whereas the beta probe can detect alpha emitters, even when there are no associated betas (as, for instance, with Am-241). In fact, because DU and Th-232 emit betas, the beta probe is actually more effective at detecting these isotopes than the alpha probe. These efficiencies are used in the main body of the report to convert minimum detectable count rates (using the various analysis procedures outlined there) into minimum detectable activities for these isotopes. This is a crucial step to determining the level of hazard to which this system is sensitive.

Table 8. Efficiencies of the alpha and beta probes for the RDS-100.

ISOTOPE	ALPHA PROBE EFFICIENCY (cps/Bq)	BETA PROBE EFFICIENCY (cps/Bq)
C-14	0.00	0.07
Tc-99	0.00	0.27
Cl-36	0.00	0.62
Sr-90	0.00	1.08
Am-241	0.18	0.17
EU	0.15	0.18
DU	0.02	0.47
Th-232	0.89	3.03

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As part of its ongoing support to DSP 00002199, the RAD group at DRDC Ottawa was asked to investigate how best to use the low-volume air sampler procured by the project for the Canadian Forces. The RAD group has used this air sampler to take a number of air samples at sites around the DRDC Ottawa campus. These air samples have been analysed via a number of techniques, many of which rely on measurements of the sampler filters by the RDS-100 survey meter system also procured by the project. A scheme for data analysis is suggested, with an emphasis on simplicity and field expediency. The sensitivity of this scheme is evaluated in terms of the minimum detectable activities of a collection of isotopes, and the airborne hazard that these would pose to deployed forces. It is shown that the air sampler is capable of providing warning of airborne hazards consisting of low-mass beta- and gamma-emitting radionuclides. However, for hazards consisting of alpha-emitting transuranic elements, this system is incapable of detecting the hazard at levels corresponding to NATO or civilian action levels.

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